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A COMPUTER PROGRAM FOR BACKSCATTER
BY TARGETS COMPOSED OF CONES,
CYLINDERS, AND DISKS - 2430-5

C.E. Ryan, Jr.

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April 1968

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DEPUTY FOR SURVEILLANCE AND CONTROL SYSTEMS
ELECTRONIC SYSTEMS DIVISION
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(Prepared for Contract No. AF 19(628)-67-C-0308 by The Ohio State
University, ElectroScience Laboratory, Department of Electrical
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AD669808

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FOREWORD

This report, OSURF report number 2430-5, was prepared by The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering, 1320 Kinnear Road, Columbus, Ohio. Research was conducted under Contract F 19628-67-C-0308. Lt. Nyman was the Electronic Systems Division Program Monitor for this research.

This technical report has been reviewed and is approved.

BERNARD J. FILLIATREAU
Contracting Officer
Space Defense & Command Systems Program Office

ABSTRACT

This report describes a computer program for determining the backscattered fields of a conducting body of revolution composed of sections of cones and cylinders. The target may be closed at one or both ends with circular disks. The target may have as many as 20 sections, and the program can readily be modified to handle a larger number. The backscattered field for E_θ or E_ϕ polarization is computed using wedge diffraction theory and geometrical optics. The computed results are in good agreement with experimental measurements for cones, cylinders, double cones, and conically capped cylinders.

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A COMPUTER PROGRAM FOR BACKSCATTER BY TARGETS COMPOSED OF CONES, CYLINDERS, AND DISKS

INTRODUCTION

A computer program, which computes the backscattered field of a body of revolution composed of cones, frustums, cylinders, and disks is given in Appendix I. This program is coded in Fortran IV and the cards are numbered consecutively in columns 76-80. This program has been tested for cones, cylinders, frustums, conically capped cylinders, and double cones, for $E\theta$ polarization of the incident and scattered fields. The results of these tests are presented in Reference 1. The theoretical basis for this program is described in References 1 and 2.

The function of this program is to compute the backscattered field as a function of aspect angle and/or frequency for a given target. This is accomplished by reading and storing the target description, identifying the regions of aspect angle corresponding to axial and specular directions, and applying the appropriate geometrical theory of diffraction solutions to calculate the scattered fields.^{1, 2} In the form presented here the angular pattern for a given target and frequency is computed. Modification of the program to compute a frequency curve for a given target and aspect angle is straightforward.

TARGET DESCRIPTION

The target shape is described in cylindrical coordinates by the second degree equation

$$(1) \quad F(\rho, z) = A_1\rho^2 + A_2z^2 + A_3\rho z + A_4z + A_5\rho + A_6 = 0 .$$

As this program is written to handle only targets composed of cones, frustums, cylinders and disks, the description of the profile of the target is that of a straight line segment, and may be expressed as

$$(2) \quad F(\rho, z) = A_4z + A_5\rho + A_6 = 0$$

where $A_1 = A_2 = A_3 = 0$. In addition to Eq. (2) the boundaries of each section of the target must be specified. That is, within each section of

the target the profile is specified by a set of constants A_4 , A_5 , A_6 . The next section is described by a new set of constants and so forth. As an example consider the target shown in Fig. 2. This target is composed of a cone, a cylinder, and a disk, and is a three section target. Thus a set of constants must be specified for each section and the angular boundaries of the sections specified. Figure 1 gives the relations by which the constants may be determined for each surface. The computer format for this input data will be discussed below.

If Eq. (1) is used to describe the target, i.e., any of the constants A_1 , A_2 , A_3 non-zero, this program will compute the scattered field due to the wedge type discontinuities on the target but will not calculate the correct total scattered field. This is because there is no provision in this program to calculate the geometrical optics field of a doubly curved surface. A calculation of this geometrical optics field is included in the creeping wave computer program.³

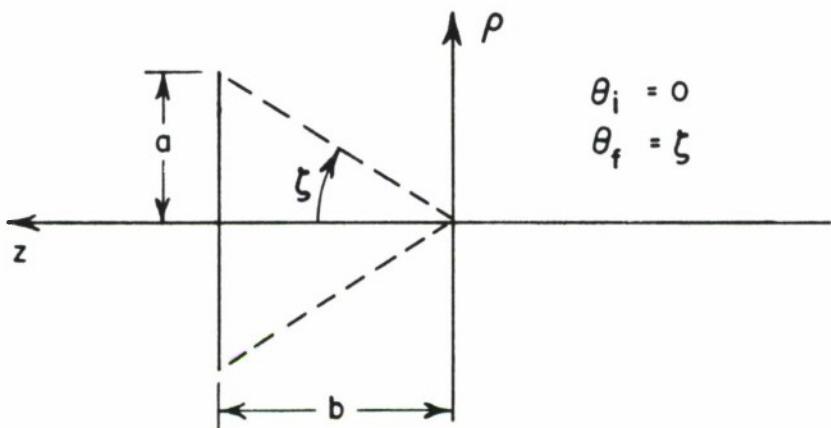
WEDGE DIFFRACTION COMPUTER PROGRAM

Referring to the computer program listing shown in Appendix I, the function of the significant sections of the program will be discussed. The card numbers associated with each section will be specified. This discussion, together with the comment cards included in the program listing, is intended to give sufficient information about the program to enable a qualified programmer to both use and modify the program. Statements which are in common use in Fortran IV such as DIMENSION, COMPLEX, and FORMAT statements will not be discussed as it is assumed that the reader has a knowledge of Fortran IV.

The COMMON declaration (0006) is used to store the constants required in Eq. (2) in the common block labelled /DATA/. This common block is used in conjunction with the unlabelled common block to transfer a particular set of constants $A_1(I)$ to $A_6(I)$ into the unlabelled common regions shared by the subroutines. This provision reduces the number of calling variables required by each subroutine.

The READ (0030-0040) statements in this block of statements read the required data and provision is also made to write out this data for the purpose of identification.

The statements 0041-0045 initialize constants which are required in the calculations.

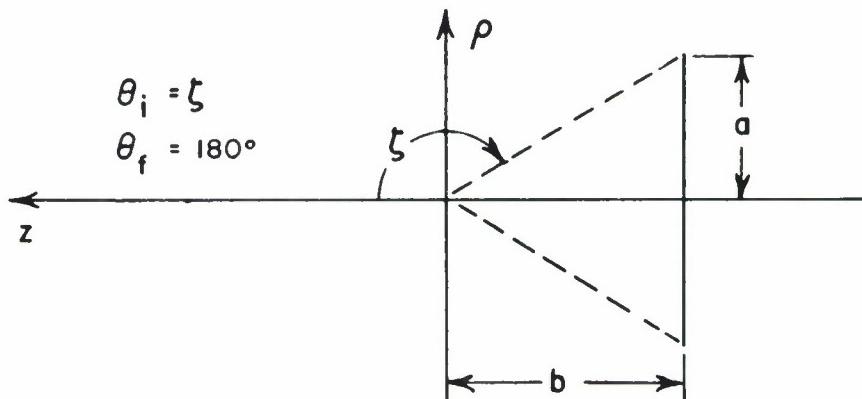


$$\zeta = \tan^{-1} \left(\frac{a}{b} \right)$$

$$A_4 = 1$$

$$A_5 = 0$$

$$A_6 = -b$$



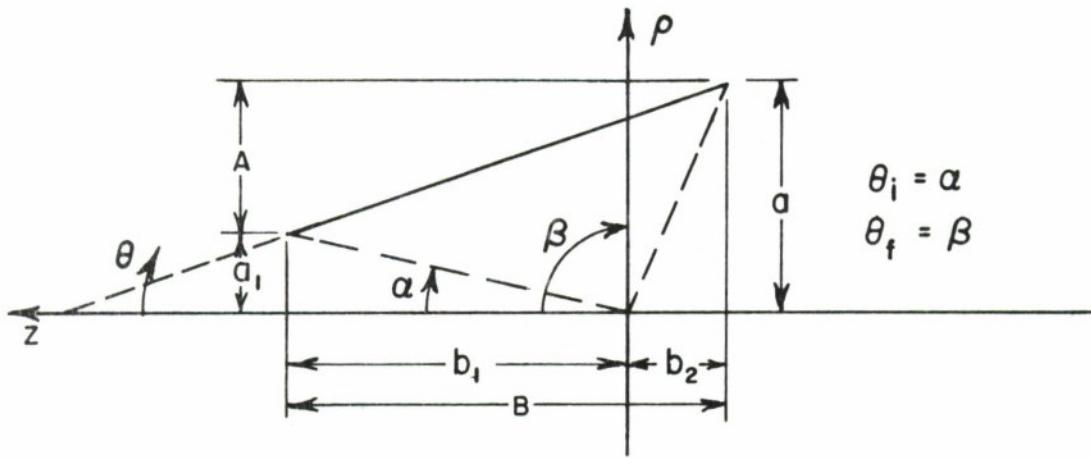
$$\zeta = 180^\circ - \tan^{-1} \left(\frac{a}{b} \right)$$

$$A_4 = -1$$

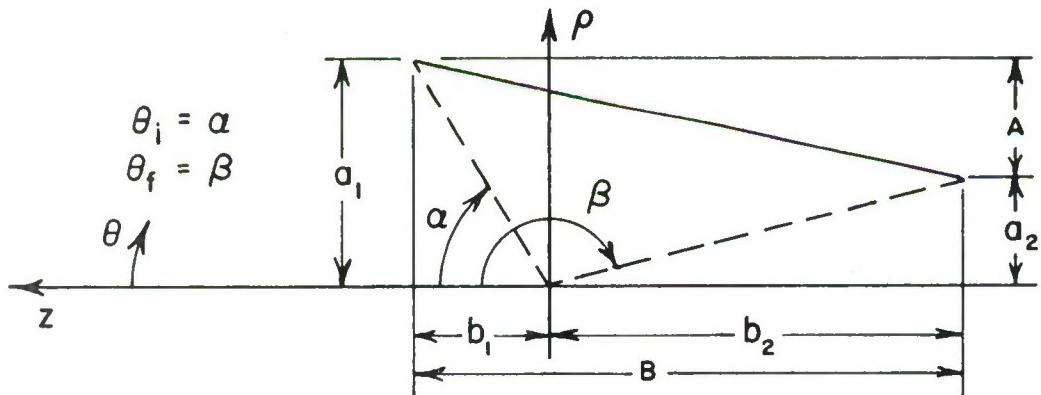
$$A_5 = 0$$

$$A_6 = -b$$

Fig. 1(a). Straight line segments and their corresponding analytic description.

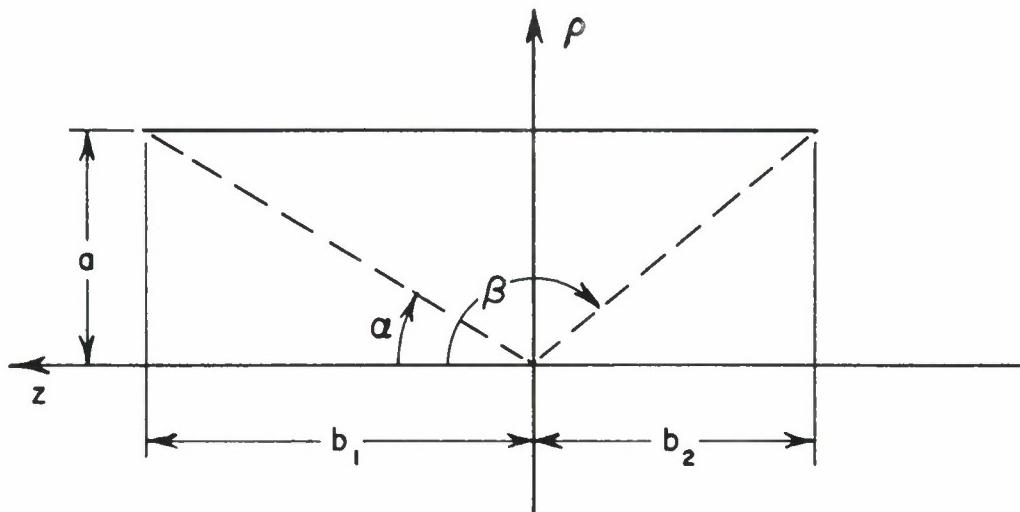


$$\begin{aligned} \alpha &= \tan^{-1}\left(\frac{a_1}{b_1}\right) & \beta &= 180^\circ - \tan^{-1}\left(\frac{a_2}{b_2}\right) \\ A_4 &= \frac{A}{B} \\ A_5 &= 1 \\ A_6 &= -\left[b\left(\frac{A}{B}\right) + a_1\right] \end{aligned}$$



$$\begin{aligned} \alpha &= \tan^{-1}\left(\frac{a_1}{b_1}\right) & \beta &= 180^\circ - \tan^{-1}\left(\frac{a_2}{b_2}\right) \\ A_4 &= -\frac{A}{B} \\ A_5 &= 1 \\ A_6 &= -\left[b_2\left(\frac{A}{B}\right) + a_2\right] \end{aligned}$$

Fig. 1(b). Straight line segments and their corresponding analytic description.



$$\theta_i = \alpha$$

$$\theta_f = \beta$$

$$\alpha = \tan^{-1} \left(\frac{a}{b_1} \right) \quad \beta = 180^\circ - \tan^{-1} \left(\frac{a}{b_2} \right)$$

$$A_4 = 0$$

$$A_5 = 1$$

$$A_6 = -a$$

Fig. 1(c). Straight line segments and their corresponding analytic description.

The next block of statements (0046 - 0108) identifies the geometrical properties of the target. The function of this section may be described by consideration of a particular target. Figure 2 shows a particular target composed of a cone-cylinder-disk. The geometrical properties of interest are the locations of the wedges, the wedge angles WA(IW), the specular directions THSX(IW), and the length of the specular line FLSX(IW). This task is accomplished by examining the normal vectors (VNX, VNY, VNZ) of the adjoining surfaces at the junction between two sections. The wedge angle is then obtained from the scalar product of the normal vectors, the specular direction is determined by checking for parallel normals at the ends of each section, and the length of the specular line is obtained using the law of cosines.

The next block of statements (0109 - 0110) remove the redundancy in specular angle which can occur when the z-axis is a specular direction. For example, in the case of a closed cylinder the directions $\theta = 0^\circ, 180^\circ$ are specular directions. In a subsequent test for a specular region in (0190 - 0196) the sine of the specular angle is taken. As the sine is periodic in 180° care must be taken that the shadowed specular region

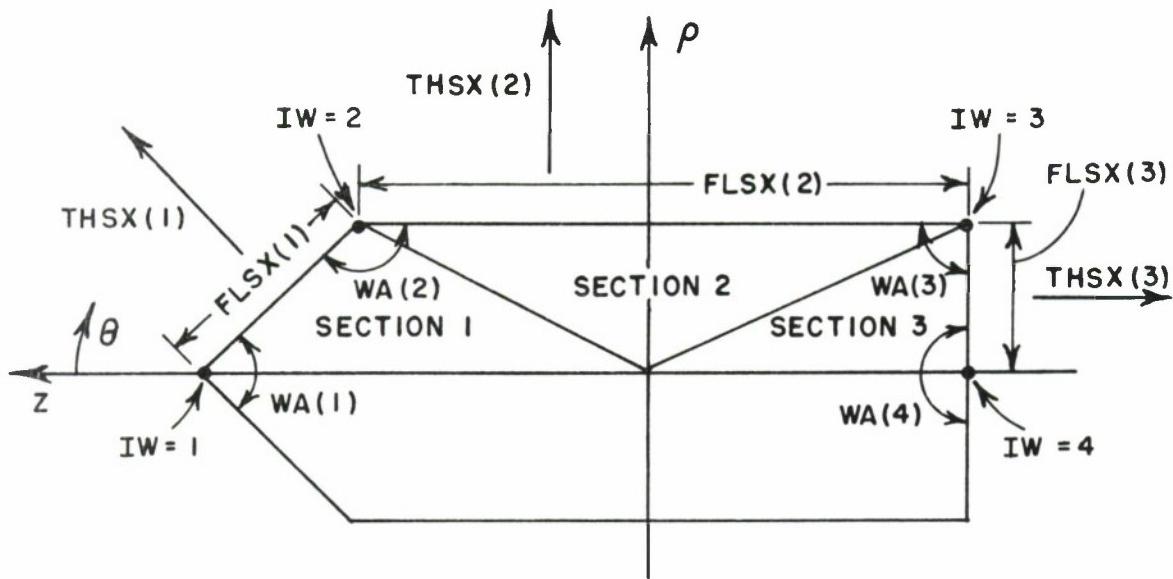


Fig. 2. A three section target-the cone-cylinder-disk.

is not included in evaluating the scattered field. This is accomplished by setting the specular angles 0° and 180° equal to 360° . These specular directions on the axis may then be evaluated using the solution for the axial caustic given in Ref. 1, and located at (0242 - 0266) in this program.

The statements (0111 - 0115) convert the computed wedge angles $WA(IWD)$ to the parameter $FN(IWD)$ required for the wedge diffraction coefficient, where IWD is the number of the particular wedge.

Having identified the required geometrical properties of the target the scattered field must now be computed. Thus the iteration for the incidence angle THT is set up (0116 - 0117) and the DO loop entered (0118). The incidence angle is incremented and the propagation vector of the incident wave is computed (0119 - 0124). Next, the total field is initialized. Then a DO loop is entered (0128) in which the total scattered field is to be obtained by summation of the individual contributions. First the location of the wedge ID is computed (0129 - 0135). Next the test parameter $BESAR$ for the axial solution region is computed. At this point a transfer to the solution for a tip scattered field is made if $ID = NWD$ (0137). A determination is now made whether the points on the

wedge ID at $\phi = 0^\circ, 180^\circ$ are illuminated or shadowed by calling the subroutine WILLY (0138 - 0143). The COMMON block is now reset (0144), having been used in the previous test, and the angle between the incident ray and the "side" of the wedge ID is computed (0145 - 0177). The phase of the backscattered field of the $\phi = 0^\circ, 180^\circ$ points on the wedge ID is calculated by the subroutine PHASE. Having completed these calculations we now move to the computation of the scattered field due to the "wedge" ID.

The first step in the field calculation is a test (0185 - 0189) to determine if the incident angle THT is in a region for which the axial solution¹ must be used. This region is bounded by the angle corresponding to the first null of the first order Bessel function $J_1(2ka \sin\theta)$. If so a transfer is made to the axial solution. Next (0190 - 0197) a test is made to determine whether the incidence angle is within a region about a specular direction specified by the first null of the $\sin(x)/x$ function. If so a transfer to the specular solution¹ is made. It is noted that as this test is made after the test for the axial region the axial solution has precedence. At this point a transfer to the solution for a tip scattered field is made if ID = 1. Locating this provision after the axial and specular region test insures that the specular region THSX(1) indicated in Fig. 2 will be included.

Having tested for regions where a special solution is required, the scattered field due to the wedge discontinuity is now computed (0201 - 0210), and added to obtain the total field. A transfer to the end of the DO loop is then made.

The solution for the specular field using the $\sin(x)/x$ formulation given in Ref. 2, is computed in 0211 - 0238. Again this field is added to obtain the total field, and upon completion transfers to the end of the DO loop.

The solution for the axially scattered fields given in Ref. 2 is computed in 0239 - 0272. Again this contribution is added to obtain the total field, and a transfer is made to the end of the DO loop.

The tip scattered fields are computed in 0273 - 0297 using the physical optics solution for the field scattered by an infinite conducting cone.⁴ Again this contribution is added to obtain the total scattered field.

Statement 301 (0297) is the end of the range of the DO loop over the number of wedges. Thus at this point the contribution of the wedge (ID) to the total field has been computed and added to the scattered field.

At the termination of the DO loop the total backscattered field EDTOT due to all contributions has been computed. Next the backscattered field and the echo area for the incident angle THT are written (0298 - 0305). After the loop on incidence angle is completed the program is terminated (0306 - 0308).

SUBROUTINES AND FUNCTIONS

Subroutine FNORM(FNVX, FNVY, FNVZ, R, THT, PHI) 0309 - 0331

This subroutine computes the normal vector (FNVX, FNVY, FNVZ) to the surface for the section whose description is in the unlabelled COMMON region. The spherical coordinates of the point at which the normal is computed are R, THT and PHI.

Subroutine FCOMM(I) 0332 - 0343

This subroutine shifts the constants describing the section I from the /DATA/COMMON into unlabelled COMMON.

Function RAD(THT) 0344 - 0363

This function calculates the distance from the origin to the surface at the angle THT. The constants describing the surface are stored in unlabelled COMMON.

Subroutine WILLY(FWI, THTI, PHI, THIN, PHIN)

This subroutine determines whether the incident wave specified by THIN, PHIN = 0., π illuminates the wedge at location THTI, PHI. If the wedge is illuminated FWI is set equal to 1., if shadowed FWI is set equal to zero.

Subroutine CROSS(X, Y, Z, A1, A2, A3, B1, B2, B3) 0384 - 0390

This subroutine computes the cross product $\bar{A} \times \bar{B}$ and returns the answer in (X, Y, Z).

Function PHASE(THTI, PHII, THTB, PHIB, RB, FK)
0391 - 0400

This function calculates the phase of the backscattered field for an incident (and scattering) direction given by THTI, PHII = 0., π , for the wedge location RB, THTB, PHIB = 0., π , with a propagation constant FK.

Function SINXX(Y) 0401 - 0408

This function computes $\sin(y)/y$.

Function DIFF1(FN, PHI, FK, BETA) 0409 - 0439

This function calculates the plane wave diffraction coefficient given in Refs. 1 and 2. FN is the wedge parameter, PHI the angular argument, FK the propagation constant, and BETA the half angle of the diffraction cone.

Function BESL0(X) 0440 - 0465

This function computes the zero order Bessel function $J_0(x)$.

Function BESL1(X) 0466 - 0491

This function computes the first order Bessel function $J_1(x)$.

Function BESL2(X) 0492 - 0501

This function computes the second order Bessel function $J_2(x)$.

INPUT DATA

A typical set of data cards is shown in Appendix II. The order of the cards is as follows:

Card #1 This card specifies in format (1I5) the number of cases to be run.

Card #2 This card specifies the number of sections of the target, in format (1I5).

Card #3 This card specifies, in order, the wavelength of the incident radiation, the starting incidence angle, the final incidence angle, the increment in angle, and the polarization factor. The wavelength is in meters, the angles in degrees, and the polarization factor is (+1.) for E_θ polarization or (-1.) for E_ϕ polarization. The format is (5F10.5).

Next N cards (N=number of target sections). These cards specify in order, the initial and final angular boundaries of the section (in radians), and the constants $A_1 \dots A_6$. The format is (8F10.5).

If the number on card number 1 is different from 1, the cards #2 to (#3 + N) are repeated. This is necessary if any of the following options are desired.

1. A change in incidence angle range.
2. A change in wavelength.
3. A change in polarization.
4. A change in target.

It is also possible to re-write the control statements in the program to provide more versatility in the control, that is, to provide for automatic looping over wavelength, or polarization. The form presented here is convenient as most experimental data is taken in the form of an echo area pattern, rather than as echo area versus frequency. A flow diagram of the program is given in Appendix IV.

CONCLUSIONS

This report is not intended to completely specify each detail of the computer program. It is intended to provide information about the program which is necessary to the use or modification of the program. The accuracy of the program has been tested for the case of E_θ (parallel) polarization as reported in Ref. 1. Tests for E_ϕ (perpendicular) polarization have not been completed, but some results are given in Appendix III.

APPENDIX I
COMPUTER PROGRAM

```

$EXECUTE      I8JOB          0000
$I8J08        GO,MAP          0001
$IBFTC WEDGD LIST,NODECK      0002
    COMPLEX EDTOT,PHASE,PHWU,PHWL,WDL,EDU,EDL,ESX,ELESS,ETIP      0003
    COMPLEX DIFFI,WBS,PBESS      0004
    COMPLEX WBSP,WBSM      0005
    COMMON RAI,RA3,R81,RA9,RA10,RA11,DATA/ARI(20),AR3(20),BR1(20),AR9(      0006
C20),AR10(20),ARI1(20)      0007
    DIMENSION THSX(20),FLSX(20),THTI(20),THTF(20)      0008
    DIMENSION VNX(20),VNY(20),VNZ(20)      0009
    DIMENSION WA(21),FN(21)      0010
1   FORMAT(1I5)          0011
2   FORMAT(5F10.5)          0012
3   FORMAT(8F10.5)          0013
4   FORMAT(3F15.8)          0014
5   FORMAT(5H RW1=F15.8,5H RW2=F15.8)      0015
6   FORMAT(6H FLSX=F15.8,6H THSX=F15.8)      0016
7   FORMAT(5H WDU=2F15.8,5H WDL=2F15.8,5H RDF=F15.8)      0017
8   FORMAT(4F15.8)          0018
9   FORMAT(1F15.8)          0019
10  FORMAT(6F15.8)          0020
11  FORMAT(6H THTD=F15.8,5H ESX=2F15.8)      0021
12  FORMAT(6H THTD=F15.8,7H ELESS=2F15.8)      0022
13  FORMAT(6H STTI=F15.8)      0023
14  FORMAT(6H ARSX=F15.8)      0024
15  FORMAT(6H PSIU=F15.8,6H PSIL=F15.8)      0025
16  FORMAT(6H FWIU=F15.8,6H FWIL=F15.8)      0026
17  FORMAT(6H THTW=F15.8,4H RW=F15.8,4H AW=F15.8,4H ZW=F15.8)      0027
18  FORMAT(27H PERPENDICULAR POLARIZATION)      0028
19  FORMAT(22H PARALLEL POLARIZATION)      0029
READ(5,1) NCS          0030
DO 600 NCSI=1,NCS+1      0031
READ(5,1)N          0032
READ(5,2)WAVE,THTS,THTE,DTHT,POL      0033
WRITE(6,2)WAVE,THTS,THTE,DTHT,POL      0034
IF(POL.LT.0.) WRITE(6,18)      0035
IF(POL.GT.0.) WRITE(6,19)      0036
READ(5,3)(THTI(1RD),THTF(IRD),AR1(1RD),AR3(IRD),BR1(IRD),AR9(IRD),      0037
CARIO(IRD),AR1I(IRD),IRD=1,N)      0038
WRITE(6,3)(THTI(J),THTF(J),AR1(J),AR3(J),BR1(J),AR9(J),AR10(J),AR1      0039
C1(J),J=1,N)      0040
PI=3.1415927      0041
TP=2.*PI      0042
PI2=PI/2.      0043
FK=TP/WAVE      0044
DEGRAD=0.01745329      0045
C   WEDGE DETERMINATION      0046
C   NUMBER OF TARGET SECTIONS=N      0047
C   CLOSED TARGET ASSUMED      0048
NWD=N+1          0049
DLARGE=0.          0050
DIA=0.          0051
TCT=0.90          0052
DO 201 IW=1,N,I      0053
THSX(IW)=TP      0054
FLSX(IW)=0.      0055
THT1=THTI(IW)      0056
THT2=THTF(IW)      0057
CALL FCMM(IW)      0058
RW1=RAD(THT1)      0059
RW2=RAD(THT2)      0060
CALL FNORM(FXI,FY1,FZ1,RW1,THT1,0.)      0061
CALL FNORM(FX2,FY2,FZ2,RW2,THT2,0.)      0062
IF(IW.EQ.1) GO TO 202      0063

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```

IW1=IW-1                                0064
THT3=THTF(IW1)                           0065
CALL FCMM(IW1)                           0066
RW3=RAD(THT3)                           0067
CALL FNORM(FX3,FY3,FZ3,RW3,THT3,0.)    0068
SPRD=FX1*FX3+FY1*FY3+FZ1*FZ3           0069
VNX(IW)=FX3                             0070
VNY(IW)=FY3                           0071
VNZ(IW)=FZ3                           0072
DANG=ARCCOS(ABS(SPRD))                 0073
IF(SPRD.LT.0.) DANG=PI-DANG           0074
WA(IW)=P1-DANG                         0075
IF(IW.EQ.N)GO TO 203                  0076
207 CONTINUE                            0077
C CHECK FOR SIN(X)/X REGION            0078
SPX=FX1*FX2+FY1*FY2+FZ1*FZ2           0079
SPX=ABS(SPX)                           0080
IF (SPX.GT.TCT)GO TO 204              0081
GO TO 500                             0082
202 CONTINUE                            0083
C CHECK FOR WEDGE ANGLE ON THE END   0084
VNX(I)=FX1                           0085
VNY(I)=FY1                           0086
VNZ(I)=FZ1                           0087
WA(I)=P1-2.*ATAN2(FX1,FZ1)           0088
GO TO 207                           0089
203 CONTINUE                            0090
C CHECK FOR WEDGE ANGLE ON THE END   0091
FZ2A=ABS(FZ2)                          0092
VNX(NWD)=FX2                          0093
VNY(NWD)=FY2                          0094
VNZ(NWD)=FZ2                          0095
WA(NWD)=P1-2.*ATAN2(FX2,FZ2A)         0096
GO TO 207                           0097
204 CONTINUE                            0098
THSX(IW)=ATAN2(FX1,FZ1)              0099
THHX=THSX(IW)                         0100
IF(IW.GT.1 .AND. ABS(THHX).EQ.0.) THSX(IW)=PI 0101
FLSX(IW)=SQRT(ABS(RW1*RW1+RW2*RW2-2.*RW1*RW2*COS(THT2-THT1))) 0102
GLSX=FLSX(IW)                         0103
WR1TE(6,5) RW1,RW2                   0104
WR1TE(6,5) THT1,THT2                0105
WR1TE(6,6) GLSX,THHX                0106
500 CONTINUE                            0107
201 CONTINUE                            0108
IF(THSX(1).LT.0.1) THSX(1)=TP        0109
IF(ABS(THSX(N)-PI).LT.0.1) THSX(N)=TP 0110
DO 208 IWD=1+NWD+1                  0111
FN(IWD)=(TP-WA(IWD))/P1             0112
FNWR=FN(IWD)                         0113
WR1TE(6,9)FNWR                      0114
208 CONTINUE                            0115
FLOOP=ABS((THTS-THTE)/DTHT)          0116
LOOP=FLOOP+1.                         0117
DO 400 LP=1+LOOP+1                  0118
FLP=LP                               0119
THTD=(FLP-1.)*DTHT                  0120
THT=DEGRAD*THTD                      0121
VX=-SIN(THT)                         0122
VY=0.                                 0123
VZ=-COS(THT)                         0124
C PARALLEL POLARIZATION             0125
EDTOT=(0.,0.)                         0126
IDSX=0                                0127

```

```

DO 301 1D=1,NWD+1          0128
THTW=THTI(1D)              0129
CALL FCOMM(1D)              0130
1F(1D.EQ.NWD) THTW=THTF(N) 0131
RW=RAD(THTW)                0132
AW=RW*SIN(THTW)             0133
ZW=RW*COS(THTW)             0134
WR1TE(6,17) THTW,RW,Aw,ZW   0135
BESAR=2.*FK*AW              0136
1F(1D.EQ.NWD) GO TO 305    0137
IF(THT.LT.PI2.AND.1D.GT.1) CALL FCOMM(1D-1) 0138
CALL WILLY(FW1,THTW,0.,THT,0.) 0139
FW1U=FW1                   0140
CALL WILLY(FW1,THTW,P1,THT,0.) 0141
FW1L=FW1                   0142
WR1TE(6,16) FW1U,FW1L       0143
CALL FCOMM(1D)              0144
306 CONTINUE                 0145
C FIND INCIDENCE ANGLE ON WEDGE 0146
C INCIDENCE VECTOR VX,VY,VZ    0147
VXM=-VX                     0148
VYM=-VY                     0149
VZM=-VZ                     0150
1F(THT.GT.PI2) GO TO 309    0151
SPRD=VXM*VNX(1D)+VZM*VNZ(1D) 0152
CALL CROSS(BX,BY,BZ,VXM,VYM,VZM,VNX(1D),VNY(1D),VNZ(1D)) 0153
DANG=ARCOS(SPRD)            0154
SIGN=-1.                     0155
1F(BY.LT.0.) SIGN=1.         0156
PSIU=P12+SIGN*DANG          0157
SPRD=-VXM*VNX(1D)+VZM*VNZ(1D) 0158
CALL CROSS(BX,BY,BZ,VXM,VYM,VZM,-VNX(1D),VNY(1D),VNZ(1D)) 0159
DANG=ARCOS(SPRD)            0160
SIGN=1.                      0161
1F(BY.LT.0.) SIGN=-1.        0162
PS1L=P12+SIGN*DANG          0163
GO TO 310                   0164
309 CONTINUE                 0165
CALL FNORM(FTX,FTY,FTZ,RW,THT,0.) 0166
SPRD=VXM*FTX+VYM*FTY+VZM*FTZ 0167
CALL CROSS(BX,BY,BZ,VXM,VYM,VZM,FTX,FTY,FTZ) 0168
DANG=ARCOS(SPRD)            0169
SIGN=1.                      0170
1F(BY.LT.0.) SIGN=-1.        0171
PSIU=P12+SIGN*DANG          0172
SPRD=-VXM*FTX+VYM*FTY+VZM*FTZ 0173
DANG=ARCOS(SPRD)            0174
PSIL=P12-DANG               0175
310 CONTINUE                 0176
WR1TE(6,15)PSIU,PSIL        0177
C DETERMINE PHASE OF WEDGE   0178
PHWU=PHASE(THT,0.,THTN,0.,RW,FK) 0179
PHWL=PHASE(THT,0.,THTL,P1,RW,FK) 0180
PSUP=2.*PSIU                 0181
PSUM=0.                      0182
PSLP=2.*PSIL                 0183
PSLM=0.                      0184
C BESSLO TEST                0185
STTO=3.8317/BESAR           0186
STT1=SIN(THT)                0187
WR1TE(6,13) STT1              0188
1F(STT1.LT.STTC)GO TO 302    0189
C SIN(X)/X TEST              0190
1DX=1D                         0191

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```

T1=ABS(THSX(1DX)-THT) 0192
IF(T1.GT.P12) T1=P12 0193
ARSX=2.*FK*FLSX(1DX)*SIN(T1) 0194
WRITE(6,14)ARSX 0195
IF(ARSX.LT.P1)GOTO 304 0196
303 CONTINUE 0197
NCHECK=303 0198
WRITE(6,1) NCHECK 0199
IF(1D.EO.1) GO TO 305 0200
C CALCULATE DIFFRACTED FIELDS 0201
WDU=D1FF1(FN(ID),PSUP,FK,P12)+POL*D1FF1(FN(ID),PSUM,FK,P12) 0202
IF(1D.EO.1DSX) WDU=(0.,C.) 0203
WDL=D1FF1(FN(ID),PSLP,FK,P12)+POL*D1FF1(FN(ID),PSLM,FK,P12) 0204
RDF=SQRT(ABS(AW/(2.*SIN(THT)))) 0205
WRITE(6,7) WDU,WDL,RDF 0206
EDU=RDF*PHWU*WDU*FW1U 0207
EDL=RDF*PHWL*WDL*FW1L 0208
EDTOT=EDTOT+EDU+EDL 0209
GO TO 301 0210
304 CONTINUE 0211
NCHECK=304 0212
WRITE(6,1) NCHECK 0213
C COMPUTE SIN(X)/X CONTRIBUTION 0214
C COMPUTE PEAK RETURN USING AVERAGE OF GAUSSIAN CURVATURE 0215
RW1=RW 0216
RW2=RAD(THTF(ID)) 0217
AW1=AW 0218
AW2=RW2*SIN(THTF(ID)) 0219
TAW=ABS(AW1-AW2) 0220
IF(TAW.LT.0.1) GO TO 307 0221
RH1=AW1/SIN(THT) 0222
RH2=AW2/SIN(THT) 0223
RH1=ABS(RH1) 0224
RH2=ABS(RH2) 0225
RSH1=SORT(RH1) 0226
RSH2=SQRT(RH2) 0227
PEAK=ABS(RSH1*RH1-RSH2*RH2)*FLSX(1D)*I.414/(3.*ABS(RH1-RH2)) 0228
PEAK=FK*PEAK 0229
GO TO 308 0230
307 PEAK=SQRT(AW1/2.)*FK*FLSX(1D) 0231
308 CONTINUE 0232
ESX=-PEAK*SINXX(ARSX)/SORT(TP*FK) 0233
ESX=ESX*PHASE(THT,0.,THTW,0.,RW,FK) 0234
1DSX=1D+I 0235
WRITE(6,11) THTD,ESX 0236
EDTOT=EDTOT+ESX 0237
GO TO 301 0238
302 CONTINUE 0239
NCHECK=302 0240
WRITE(6,1) NCHECK 0241
C COMPUTE FIELD USING BESSEL FUNCTIONS 0242
SBSS=0.5 0243
PKSPC=FK*AW*AW 0244
PKBSS=AW 0245
ARGBS=BESAR*SIN(THT) 0246
IF(ABS(ARGBS).GT.0.05) SBSS=BESL1(ARGBS)/ARGBS 0247
CALL FNORM(F1X,F1Y,F1Z,RW,THTW,0.) 0248
PSUB=2.**(P12-ARCOS(ABS(F1Z))) 0249
IF(THT.LT.P12) PSUB=2.**(P12-ARCOS(VNZ(ID))) 0250
WBS=D1FF1(FN(ID),PSUB,FK,P12) 0251
PBESS=PHASE(THT,0.,0.,0.,ZW,FK) 0252
SHBDT=CABS(WBS)-0.5 0253
IF(ABS(SHBDT).LT.0.05) GO TO 321 0254
WBS=WBS*SQRT(TP*FK) 0255

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COST=COS(THT) 0256
WBSP=DIFFI(FN(ID),0.,FK,PI2)+DIFFI(FN(ID),PSUB,FK,PI2) 0257
WBSM=DIFFI(FN(ID),0.,FK,PI2)-DIFFI(FN(ID),PSUB,FK,PI2) 0258
WBSP=WBSP*SQRT(FK*TP) 0259
WBSM=WBSM*SQRT(TP*FK) 0260
WBS=-COST*COST*WBSM*SBSS+WBSP*(SBSS-BESL2(ARGBS)) 0261
IF(POL.LT.0.) WBS=COST*COST*WBSP*SBSS-WBSM*(SBSS-BESL2(ARGBS)) 0262
EBESS=(0.,-1.)*PKBSS*PBESS*WBS 0263
IF(FWIU.EQ.0..AND.FWIL.EQ.0.) EBESS=(0.,0.) 0264
IF(FWIU.GT.0..AND.FWIL.EQ.0.) EBESS=0.5*EBESS 0265
GO TO 322 0266
321 CONTINUE 0267
EBESS=(0.,-1.)*PKSPC*PBESS*SBSS 0268
322 CONTINUE 0269
WRITE(6,12) THTD,EBESS 0270
EDTOT=EDTOT+EBESS 0271
GO TO 301 0272
305 CONTINUE 0273
NCHECK=305 0274
WRITE(6,1) NCHECK 0275
C COMPUTE TIP CONTRIBUTION AT ENDS 0276
C TO FIRST ORDER TIP CONTRIBUTIONS ARE NEGLEGIBLE 0277
THTCN=THT 0278
IF(THT.GT.PI2) THTCN=PI-THT 0279
HFCA=0.5*WA(ID) 0280
TCNA=PI2-HFCA 0281
TCNAA=ABS(THTCN-TCNA) 0282
IF(TCNAA.LT.0.1745) GO TO 312 0283
IF(ABS(HFCA-PI2).LT.0.1745) GO TO 312 0284
TANA=TAN(HFCA) 0285
TANA2=TANA*TANA 0286
TANTH=TAN(THTCN) 0287
TANT2=TANTH*TANTH 0288
COSTH=COS(THCN) 0289
COSTH3=COSTH*COSTH*COSTH 0290
ETIP=-WAVE*TANA2/(8.*PI*COSTH3*(1.-TANA2*TANT2)) 0291
ETIP=ETIP*PHASE(THT,0.,0.,0.,ZW,FK) 0292
IF(POL.LT.0.) ETIP=-ETIP 0293
GO TO 311 0294
312 ETIP=(0.,0.) 0295
311 CONTINUE 0296
EDTOT=EDTOT+ETIP 0297
301 CONTINUE 0298
C OUTPUT SECTION 0299
WRITE(6,4) THTD,EDTOT 0300
EMAG=CABS(EDTOT) 0301
SIGMA=2.*TP*EMAG*EMAG/(WAVE*WAVE) 0302
SIGMAL=10.*ALOGIO(SIGMA) 0303
WRITE(6,4) SIGMA,SIGMAL 0304
400 CONTINUE 0305
600 CONTINUE 0306
STOP 0307
END 0308
$IBFTC FFNRM LIST,NODECK 0309
SUBROUTINE FNORM(FNVX,FNVY,FNVZ,R,THT,PHI) 0310
C INPUT R,THT,PHI 0311
COMMON AR1,AR3,BR1,AR9,ARI0,ARI1 0312
ST=SIN(THT) 0313
CT=COS(THT) 0314
SP=SIN(PHI) 0315
CP=COS(PHI) 0316
U=ARI*ST*ST+AR3*CT*CT+BRI*ST*CT 0317
V=AR9*CT+ARI0*ST 0318
UTH=2.*(ARI-AR3)*ST*CT+BRI*(CT*CT-ST*ST) 0319

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VTH=-AR9*ST+AR10*CT          0320
F1=2.*R*U+V                   0321
F2=R*UTH+VTH                 0322
FX=ST*CP*F1+CT*CP*F2         0323
FY=ST*SP*F1+CT*SP*F2         0324
FZ=CT*F1-ST*F2               0325
FN=SQRT(FX*FX+FY*FY+FZ*FZ)  0326
FNVX=FX/FN                   0327
FNVY=FY/FN                   0328
FNVZ=FZ/FN                   0329
RETURN                         0330
END                           0331
$IBFTC FCOMM. LIST, NODECK
SUBROUTINE FCOMM(I)           0332
COMMON RA1,RA3,RB1,RA9,RA10,RA11//DATA/AR1(20),AR3(20),BR1(20),AR9( 0334
C20),AR10(20),AR11(20)       0335
RA1=AR1(I)                   0336
RA3=AR3(I)                   0337
RB1=BR1(I)                   0338
RA9=AR9(I)                   0339
RA10=AR10(I)                 0340
RA11=AR11(I)                 0341
RETURN                         0342
END                           0343
$IBFTC RADD     LIST, NODECK
FUNCTION RAD(THT)             0344
CALCULATE R                  0345
C   COMMON AR1,AR3,BRI,AR9,AR10,AR11
R=0.                           0346
ST=SIN(THT)                  0347
CT=COS(THT)                  0348
C1=AR1*ST*ST+AR3*CT*CT+BRI*ST*CT 0349
C2=AR9*CT+AR10*ST            0350
C3=AR11                       0351
IF(C1.EQ.0.) GO TO 11        0352
ARG=SQRT(C2*C2-4.*C1*C3)    0353
R=(-C2+ARG)/(2.*C1)          0354
R2=(-C2-ARG)/(2.*C1)         0355
IF(R2.LT.R.AND.R2.GT.0.) R=R2 0356
GO TO 12                      0357
11 R=-C3/C2                  0358
12 RAD=ABS(R)                0359
RETURN                         0360
END                           0361
$IBFTC WILLY. LIST, NODECK
SUBROUTINE WILLY(FWI,THTI,PHI,THIN,PHIN) 0362
C   INPUT THTI, PHI, THIN, PHIN           0363
C   FWI=0.  WEDGE IN SHADOW              0364
C   FWI=1.  WEDGE ILLUMINATED            0365
COMMON AR1,AR3,BRI,AR9,AR10,AR11 0366
PI=3.1415927                  0367
PI2=1.5707963                 0368
R=RAD(THTI)                   0369
CALL FNORM(FNX,FNY,FNZ,R,THTI,PHI) 0370
TH=THIN                        0371
XIN=SIN(TH)*COS(PHIN)          0372
YIN=0.                          0373
ZIN=COS(TH)                    0374
SPRD=FNX*XIN+FNY*YIN+FNZ*ZIN 0375
FWI=1.                          0376
IF(SPRD.LT.0.) FWI=0.            0377
CONTINUE                        0378
RETURN                         0379
END                           0380

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```

$IBFTC CROSS. LIST,NODECK 0384
    SUBROUTINE CROSS(X,Y,Z,A1,A2,A3,B1,B2,B3) 0385
    X=A2*B3-A3*B2 0386
    Y=A3*B1-A1*B3 0387
    Z=A1*B2-A2*B1 0388
    RETURN 0389
    END 0390
$IBFTC PHAS. LIST,NODECK 0391
    COMPLEX FUNCTION PHASE(THTI,PHII,THTB,PHIB,RB,FK) 0392
    FS=I. 0393
    TEST=ABS(PHII-PHIB) 0394
    IF(TEST.EQ.0.) FS=-I. 0395
    FL=2.*RB*COS(THTI+FS*THTB) 0396
    FKL=FK*FL 0397
    PHASE=CMPLX(COS(FKL),SIN(FKL)) 0398
    RETURN 0399
    END 0400
$IBFTC SINXX. LIST,NODECK 0401
    FUNCTIONSINXX(Y) 0402
    C SIN(X)/X FUNCTION 0403
    Z=Y*Y 0404
    SINXX=(1.-(Z/6.)*(1.-(Z/20.)*(1.-(Z/42.)*(1.-(Z/72.)*(1.-(Z/110.)* 0405
    2(1.-(Z/156.)*(1.-(Z/182.))))))) 0406
    RETURN 0407
    END 0408
$IBFTC DIFCN LIST,NODECK 0409
    COMPLEX FUNCTION DIFF1(FN,PHI,FK,BETA) 0410
    C SINGLE DIFFRACTION FUNCTION DIFF1 0411
    C FN=WEDGE ANGLE, PHI=ARGUMENT, BETA=CONE ANGLE 0412
    COMPLEX EXPH 0413
    PI=3.1415927 0414
    TP=2.*PI 0415
    PI4=PI/4. 0416
    PIF=PI/FN 0417
    PHN=PHI/FN 0418
    PHIA=ABS(PHI) 0419
    EXPH=CEXP((0.,-1.)*PI4) 0420
    SINB=SIN(BETA) 0421
    SINB=ABS(SINB) 0422
    IF(SINB.LT..001) GO TO 3 0423
    IF(ABS(PHIA-PI).LT..0.1) GO TO 1 0424
    T1=COS(PIF) 0425
    T2=COS(PHN) 0426
    T3=SIN(PIF) 0427
    T4=TI-T2 0428
    T4A=ABS(T4) 0429
    IF(T4A.LT..001) GO TO 3 0430
    DIFF1=EXPH*T3/(FN*SINB*T4) 0431
    DIFF1=DIFF1/SQRT(TP*FK) 0432
    GO TO 2 0433
    I DIFF1=0.5/SINB 0434
    GO TO 2 0435
    3 DIFF1=1000. 0436
    2 CONTINUE 0437
    RETURN 0438
    END 0439
$IBFTC BESL0. LIST,NODECK 0440
    FUNCTION BESL0(X) 0441
    C (X.GT.0.) 0442
    Z=ABS(X) 0443
    Y=X/3. 0444
    Y2=Y*Y 0445
    Y3=Y2*Y 0446
    Y4=Y2*Y2 0447

```

```

Y5=Y3*Y2                                0448
Y6=Y4*Y2                                0449
Y8=Y6*Y2                                0450
Y10=Y8*Y2                                0451
Y12=Y10*Y2                               0452
IF(Z.GT.3.)GO TO 10                      0453
8ESL0=1.-2.2499997*Y2+1.2656208*Y4-.3163866*Y6+.0444479*Y8-.003944 0454
24*Y10-.00024846*Y12                     0455
GO TO 11                                 0456
10  CONTINUE                             0457
F=.79788456-(.00000077/Y)-(.00552740/Y3)-(.00009512/Y3)+(.00137237 0458
2/Y4)-(.00072805/Y5)+(.00014476/Y6)  0459
T=X-.78539316-(.04156397/Y)-(.00003954/Y2)+(.00262573/Y3)-(.000541 0460
225/Y4)-(.00029333/Y5)+(.00013558/Y6) 0461
8ESL0=F*COS(T)/SQRT(X)                  0462
11  CONTINUE                             0463
RETURN                                  0464
END                                     0465
$1BFTC BESL1. LIST,NODECK               0466
FUNCTION BESL1(X)                         0467
C   POLYNOMIAL APPROXIMATION X.GT.0.    0468
Y=X/3.                                    0469
Y2=Y*Y                                   0470
Y3=Y2*Y                                 0471
Y4=Y3*Y                                 0472
Y5=Y4*Y                                 0473
Y6=Y5*Y                                 0474
Y8=Y6*Y2                                0475
Y10=Y8*Y2                               0476
Y12=Y10*Y2                              0477
IF(X.GT.3.)GO TO 10                      0478
BESL=0.5-.56249985*Y2+.21093573*Y4-.03954289*Y6+.00443319*Y8-.0003 0479
21761*Y10+.00001109*Y12                 0480
BESL1=X*BESL                            0481
GO TO 11                                 0482
10  CONTINUE                             0483
F=.79788456+(.00000156/Y)+(.01659667/Y2)+(.00017105/Y3)-(.00249511 0484
2/Y4)+(.00113653/Y5)-(.00020033/Y6)  0485
T=X-2.35619449+(.12499612/Y)+(.00005650/Y2)-(.00637879/Y3)+(.00074 0486
2348/Y4)+(.00079824/Y5)-(.00029166/Y6) 0487
8ESL1=F*COS(T)/SQRT(X)                  0488
11  CONTINUE                             0489
RETURN                                  0490
END                                     0491
$1BFTC BESL2. LIST,NODECK               0492
FUNCTION BESL2(X)                         0493
C   (X.GT.0.)                           0494
IF(X.EQ.0.)GO TO 10                      0495
BESL2=(2.*BESL1(X)/X)-BESL0(X)          0496
GO TO 11                                 0497
10  BESL2=0.                            0498
11  CONTINUE                             0499
RETURN                                  0500
END                                     0501
$DATA                                0502

```

APPENDIX II
INPUT DATA

00002

00003

1.0	0.	180.	1.0	-1.			
0.	.785398	0.	0.	0.	2.0	1.0	-2.0
.785398	2.617	0.	0.	0.	0.	1.0	-1.0
2.617	3.1415927	0.	0.	0.	-1.0	0	-2.0

00003

1.0	0.	180.	1.0	1.0			
0.	.785398	0.	0.	0.	2.0	1.0	-2.0
.785398	2.617	0.	0.	0.	0.	1.0	-1.0
2.617	3.1415927	0.	0.	0.	-1.0	0.	-2.0

APPENDIX III COMPUTER TESTS FOR E_ϕ POLARIZATION

A limited amount of data has been obtained for the case of E_ϕ polarization. The computed results are compared with measured data for the cone and double cone in Figs. 3 and 4. The data for the cone is that of Keys and Primich⁵ and the double cone data is from Eberle and St. Clair.⁶ For the case of the cone the greatest error is in the near forward region where the single diffraction solution is used. The results in this region agree with the single diffraction results of Bechtel.⁷ The results in this region could be improved by extending the edge current formulation for the axially scattered fields to this region. In the case of the double cone the calculated echo area is in error in the region about $\theta = 90^\circ$. This is a region where the effect of edge type creeping waves¹ at the junction should be considered. These test results indicate that further extension of the theory and computer program is necessary to remove these sources of error. However, for targets which are large in terms of wavelength the accuracy will improve, as both the edge current and creeping wave effects would diminish.

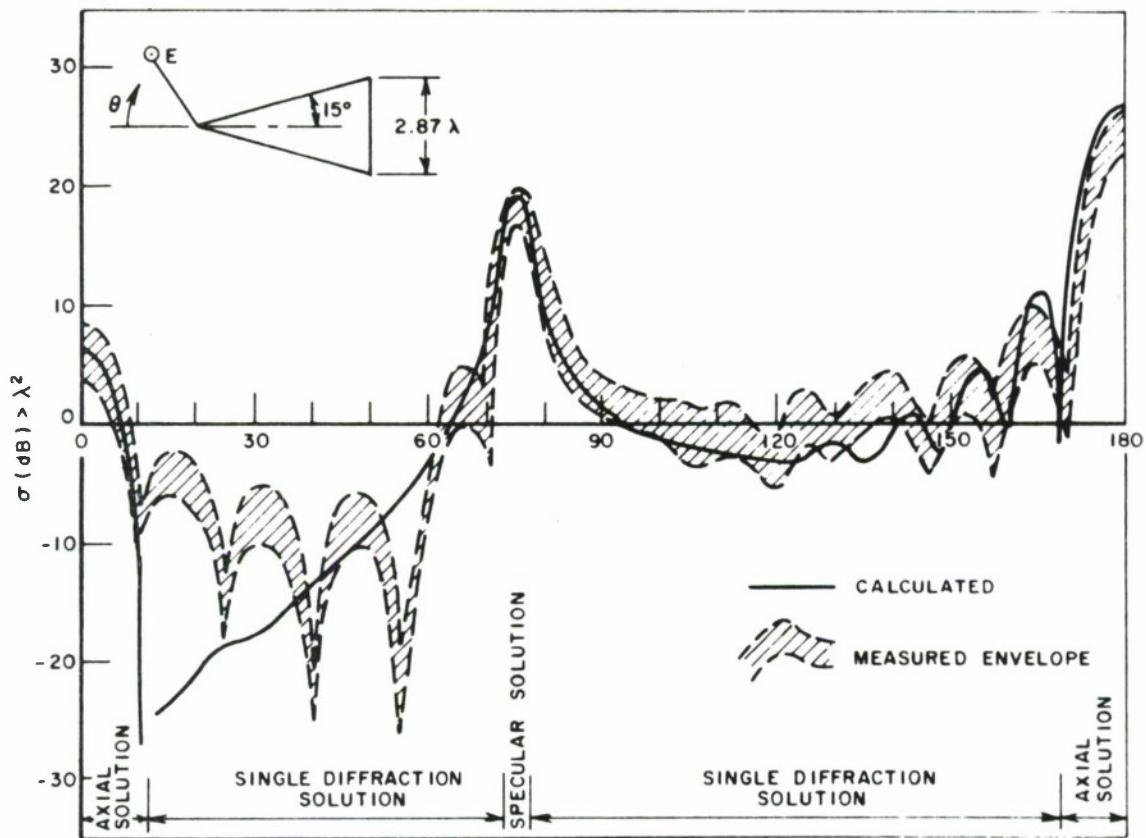


Fig. 3. Echo area of a cone- E_ϕ polarization.

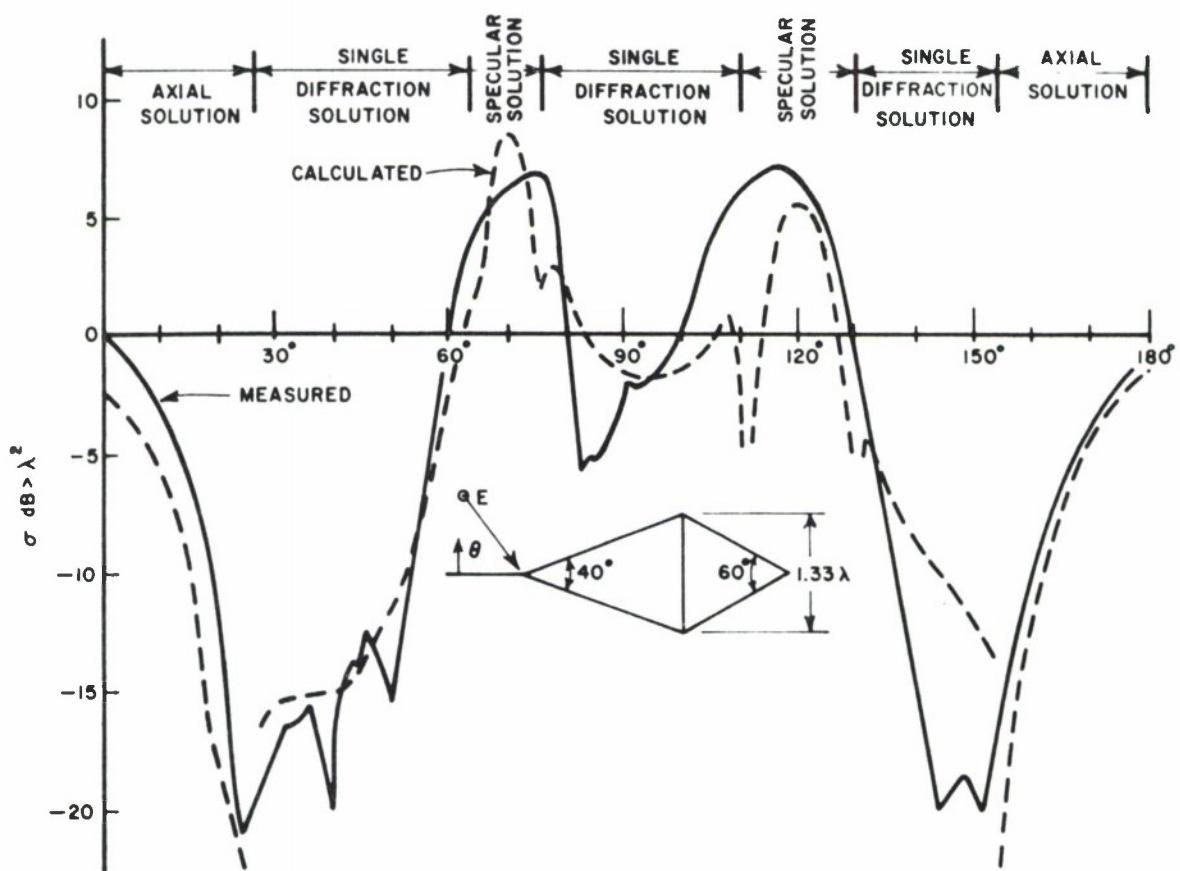
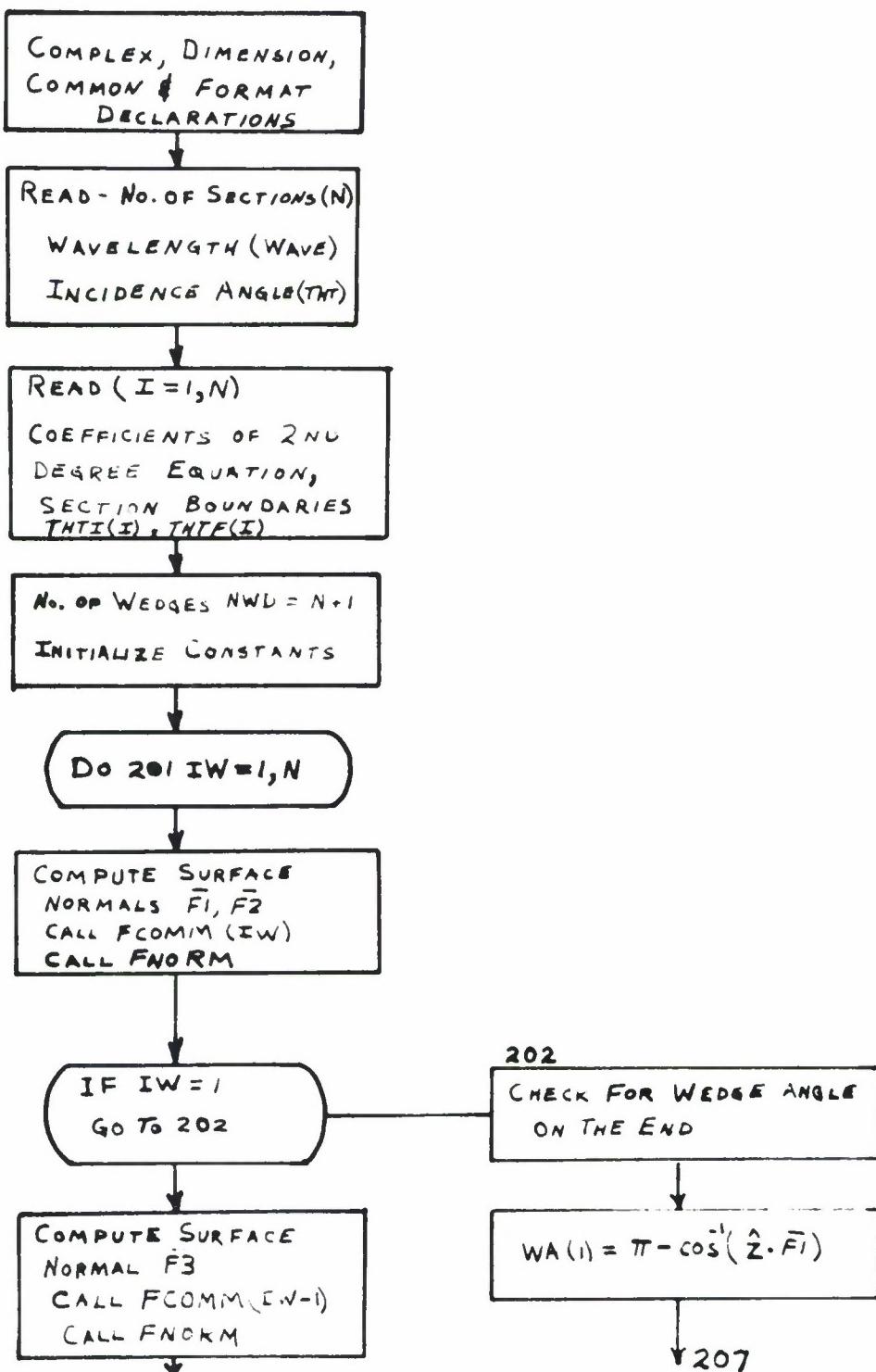


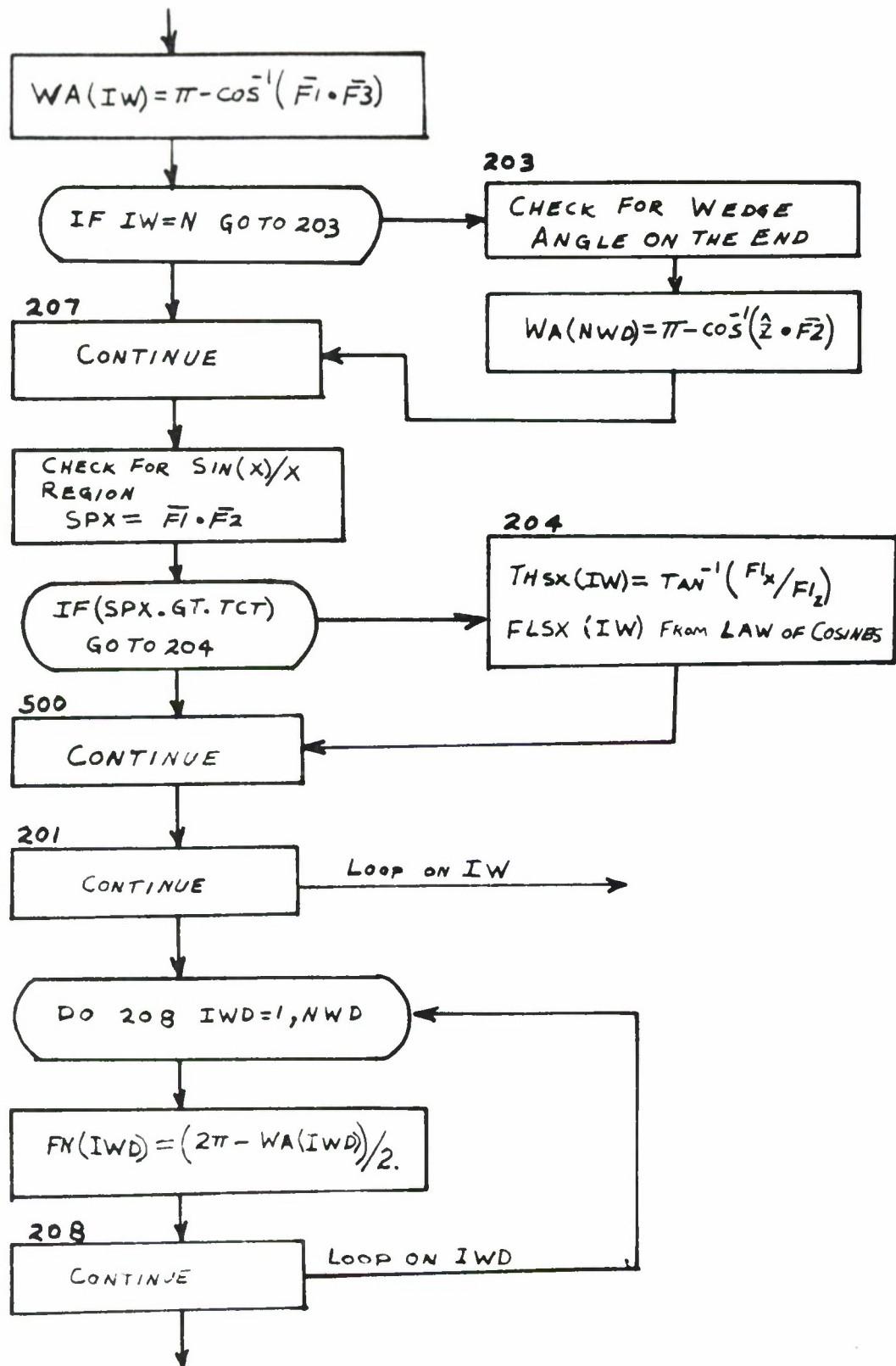
Fig. 4. Echo area of a double cone- E_ϕ polarization.

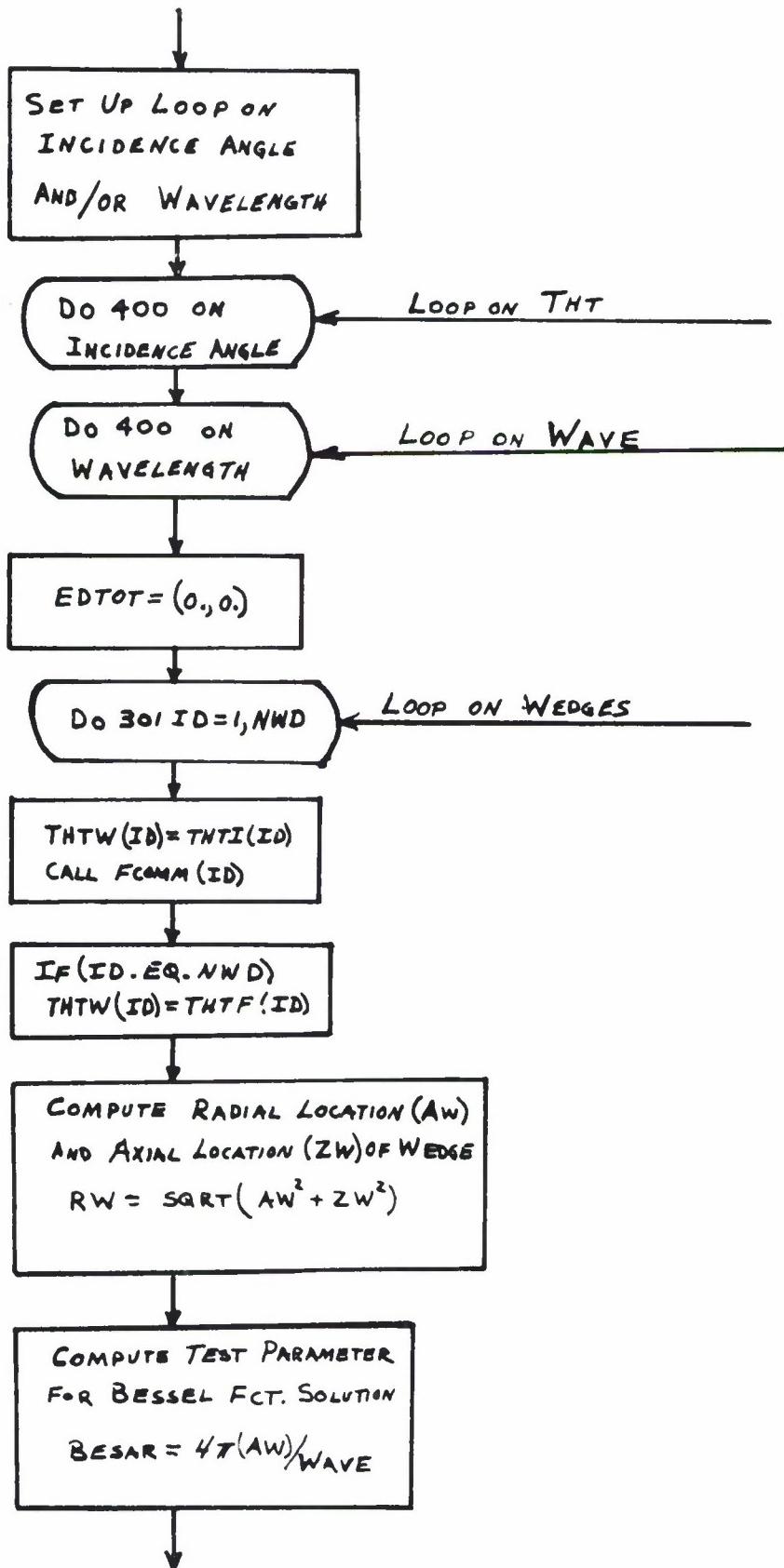
APPENDIX IV
WEDGE DIFFRACTION COMPUTER PROGRAM
FLOW DIAGRAM

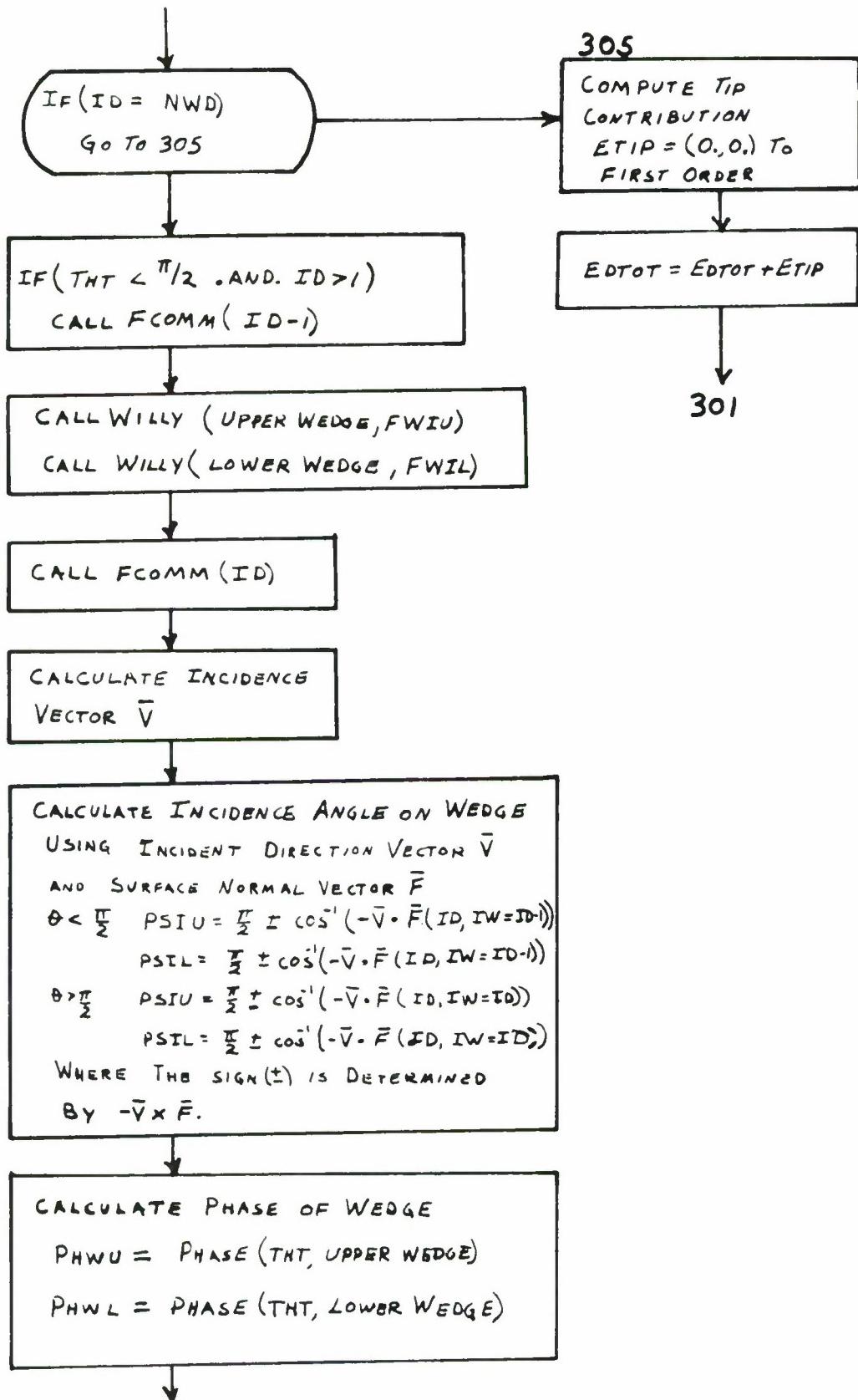
The flow diagram for the wedge diffraction Computer program WEDGD is given in Fig. 5. This flow diagram has also been presented in Ref. 1.

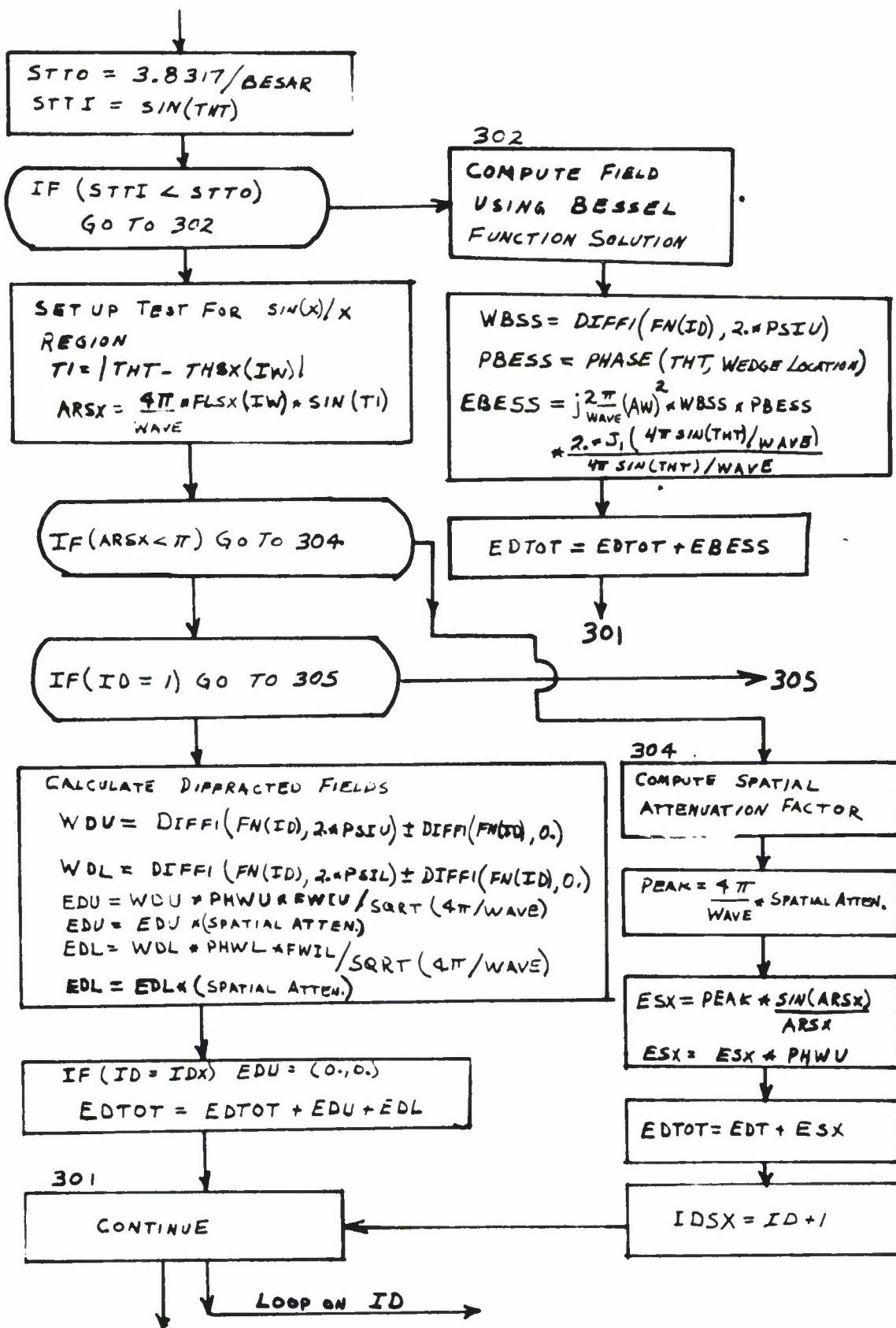
WEDGE DIFFRACTION COMPUTER PROGRAM

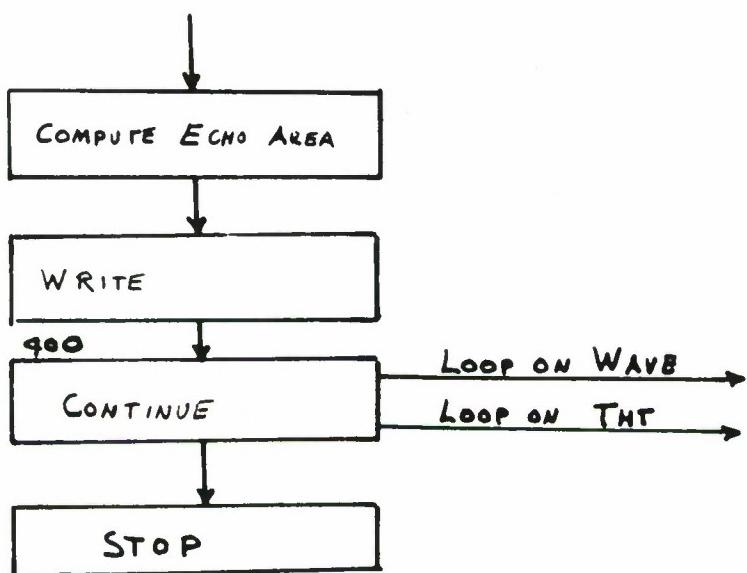












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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The Ohio State University, Department of Electrical Engineering, 1320 Kinnear Rd., Columbus, Ohio		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP N/A
3. REPORT TITLE A Computer Program for Backscatter by Targets Composed of Cones, Cylinders, and Disks		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report		
5. AUTHOR(S) (Last name, first name, initial) Ryan, C.E., Jr.		
6. REPORT DATE April 1968	7a. TOTAL NO. OF PAGES 31	7b. NO. OF REFS 6
8a. CONTRACT OR GRANT NO. F-19628-67-C-0308	9a. ORIGINATOR'S REPORT NUMBER(S) ESD-TR-68-212	
b. PROJECT NO.		
c. TASK	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. AVAILABILITY/LIMITATION NOTICES This document has been approved for public release and sale; its distribution is unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Deputy for Surveillance and Control Systems, Electronic Systems Division L.G. Hanscom Field, Bedford, Mass.	
13. ABSTRACT This report describes a computer program for determining the back-scattered fields of a conducting body of revolution composed of sections of cones and cylinders. The target may be closed at one or both ends with circular disks. The target may have as many as 20 sections, and the program can readily be modified to handle a larger number. The back-scattered field for E_θ or E_ϕ polarization is computed using wedge diffraction theory and geometrical optics. The computed results are in good agreement with experimental measurements for cones, cylinders, double cones, and conically capped cylinders.		

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Radar cross section Backscatter Surface of revolution Combination of cones, frustums, and disks Geometrical optics Diffraction theory						
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